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Energy Storage R&D at PNNL

VINCENT SPRENKLE – Technical Group Manager

Pacific Northwest National Laboratory

Northern Ohio Energy Storage and Integration Workshop

Energy Storage R&D Programs at PNNL

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DOE OE Energy Storage Program

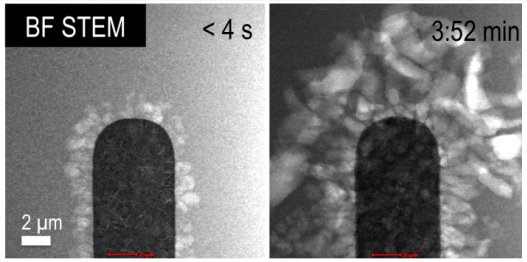
- Development of Cost Competitive Technologies
- Validated Safety and Reliability,
- Equitable Regulatory Environment
- Industry Acceptance

5 kW Redox Flow Battery

DOE BES JCESR

- Li-metal systems
- Non Aqueous Redox flow

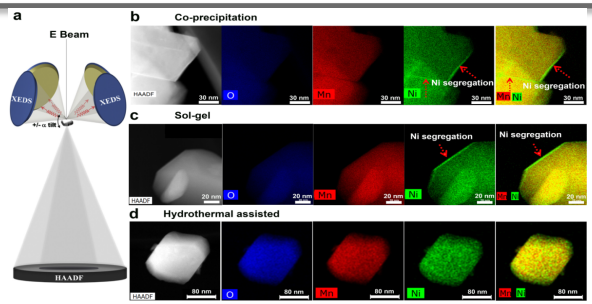
In-situ TEM of Li dendrite formation



DOE EERE Vehicle Technologies Office

- High Voltage Li-ion cathodes
- Si-anode development
- Li-S systems

Understanding Impact of uniformity on Voltage Fade



Army Corp of Engineers/DOD

- Micro fish tag battery
- Integrated systems development

Micro fish tag sensor and battery

OE Energy Storage Program - Cost Competitive Technologies

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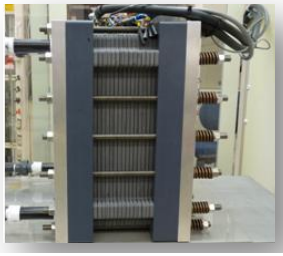
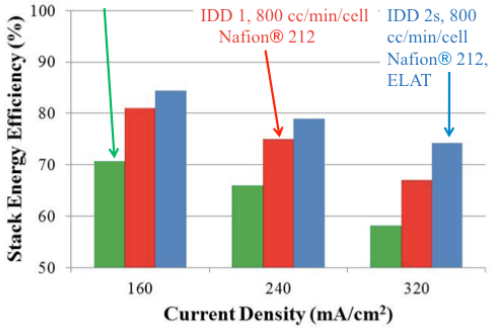
- *Develop material and system enhancements to resolve key cost and performance challenges for energy storage devices.*

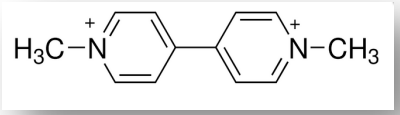
Redox Flow

High Performance V/V
5 kW Prototype



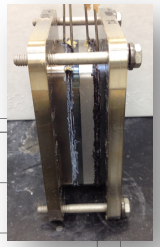


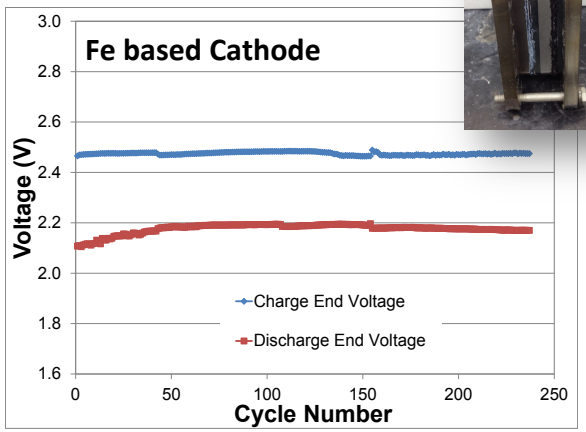
Aqueous Soluble Organic (ASO)



Sodium Batteries

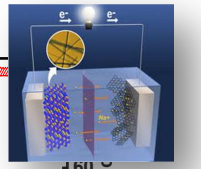
IT Na Metal Halide 190°C

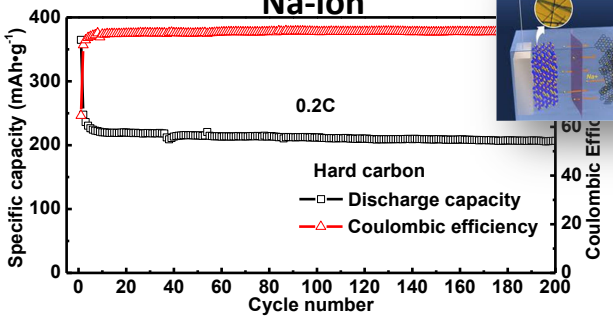




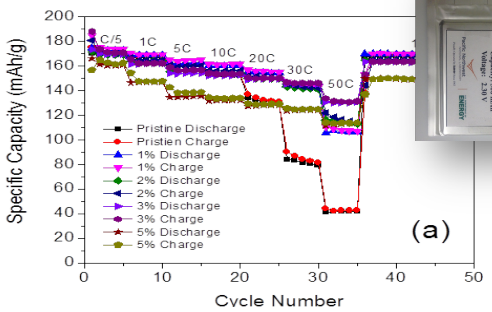
RT Na Battery
L. Shaw - IIT

Na-ion





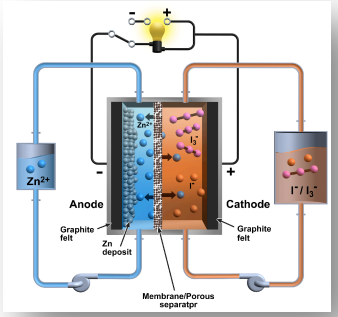
Li-ion



Solid State Li-ion
PNNL + X. Liu- WVU

Novel Chemistries

Zn-I_2 Flow Battery



OE Energy Storage Program - Example Cost Competitive Technologies

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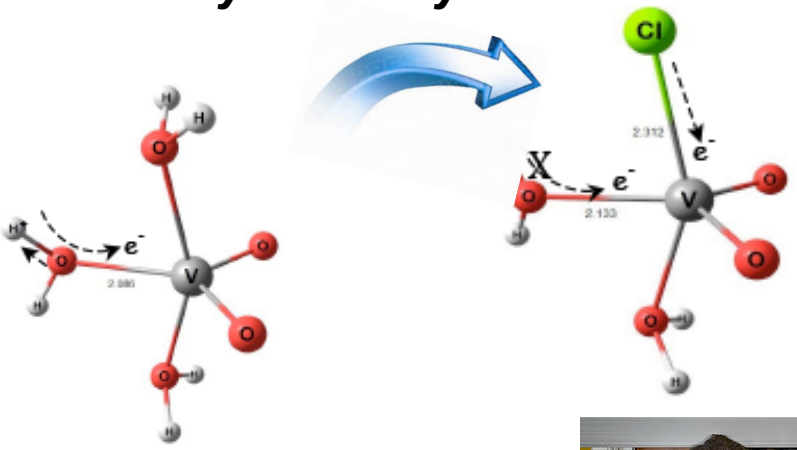
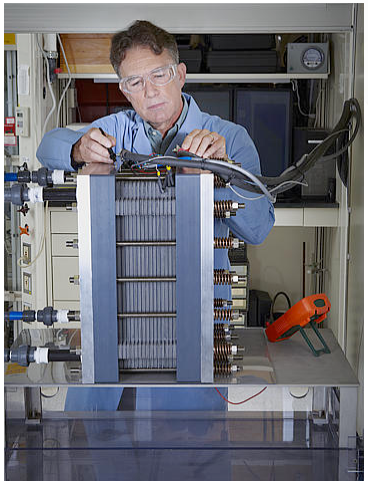
- ***Mixed Acid Redox Flow Battery Electrolyte.***

Collaboration with EMSL/FCSD on standard sulfuric electrolyte: deprotonation leads to precipitation at elevated temperatures



HCl addition prevents deprotonation increasing temperature stability by 80% and energy density by 70%



PNNL kW lab scale demonstration of technology

WA Governor Jay Inslee, UniEnergy CEO Gary Yang, OE Asst. Sec. Pat Hoffman at CEF kickoff June 2014

Avista/UniEnergy 1 MW/3 MWh System installation February 2015.

OE Energy Storage Program - Validated Safety and Reliability

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- *For energy storage systems to be ubiquitously accepted the technology must be demonstrated to be safe and reliable*

- **Energy Storage Safety Working Group**

1) Validation & Risk Assessment R&D	2) Codes & Standards	3) Outreach & Incident Response
POC: Summer Ferreira, SNL	**POC:** Dave Conover, PNNL	**POC:** David Rosewater, SNL

Codes 101

CSR Inventory

- **Energy Storage Reliability**

  Planning workshop in FY16 with stakeholders to develop technology roadmap for validated reliability of energy storage systems.

Sandia National Laboratories

OE Energy Storage Program - Equitable Regulatory Environment

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- *Value propositions for grid storage depend on reducing institutional and regulatory hurdles to levels comparable with those of other grid resources.*

- **PNW Energy Storage Workshop**

  Hosted Pacific Northwest utility regulatory commission workshop on energy storage with commissioners and staff from WA, OR, ID, and MT. (July 2015)

  Provided information to commissions on valuation of energy storage assets.

  - Presented at Washington UTC Energy Storage Workshop (Aug 2015)

  - Planning expansion of Regional Workshops in FY16.

July 2015 Pacific Northwest Regulators Workshop Participants - Richland, WA

OE Energy Storage Program - Industry Acceptance

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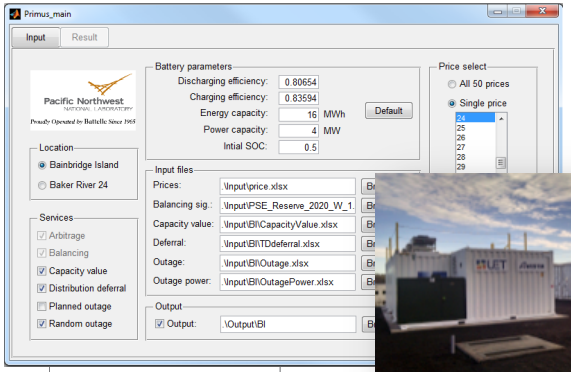
- *Demonstrating the value, performance, and reliability of energy storage systems in both controlled and fielded deployments.*

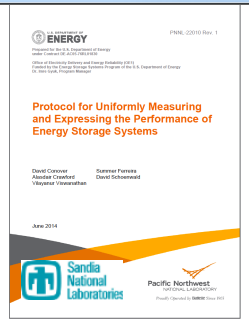
- **WA State Clean Energy Fund**
  - PNNL evaluating use case economics for 7 MW/ 15MWh of energy storage deployments in WA.
  - Utilizing Battery Storage Evaluation Tool (BSET) developed under BPA TIP program with Primus/PGE and DOE OE.

- **Performance Protocols**
  - In coordination with SNL and industry working group, lead development of performance protocols for Volt-VAR support, Power Quality and Frequency Control (FY15)
  - SNL/PNNL have completed 7 applications to date, and nearing completion on the 8th

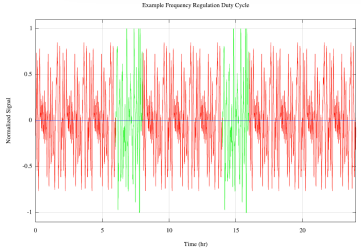
- **BPA demonstrations**
  - Completed assessment of 120kW/500kWh Powin Li-ion system for wind integration (ENW), demand management (City of Richland), Solar Integration (PNNL).



WA CEF



Performance Protocols



Testing 125 kW/500 kWh Powin ESS at PNNL Solar Array.

OE Energy Storage Program - Example Industry Acceptance

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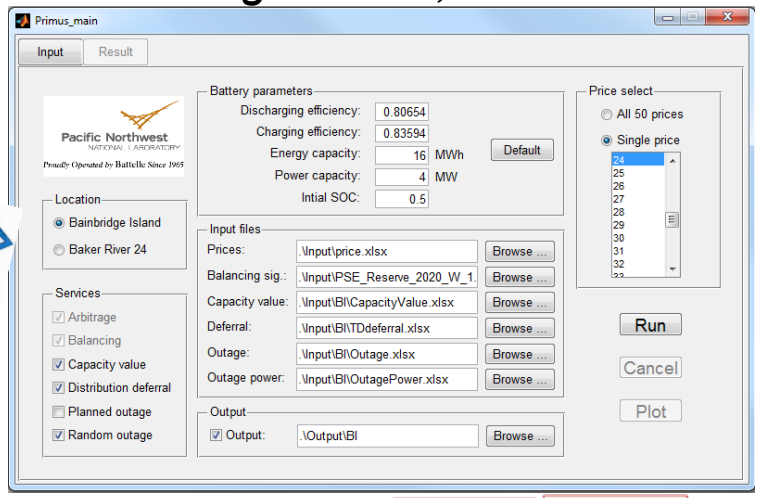
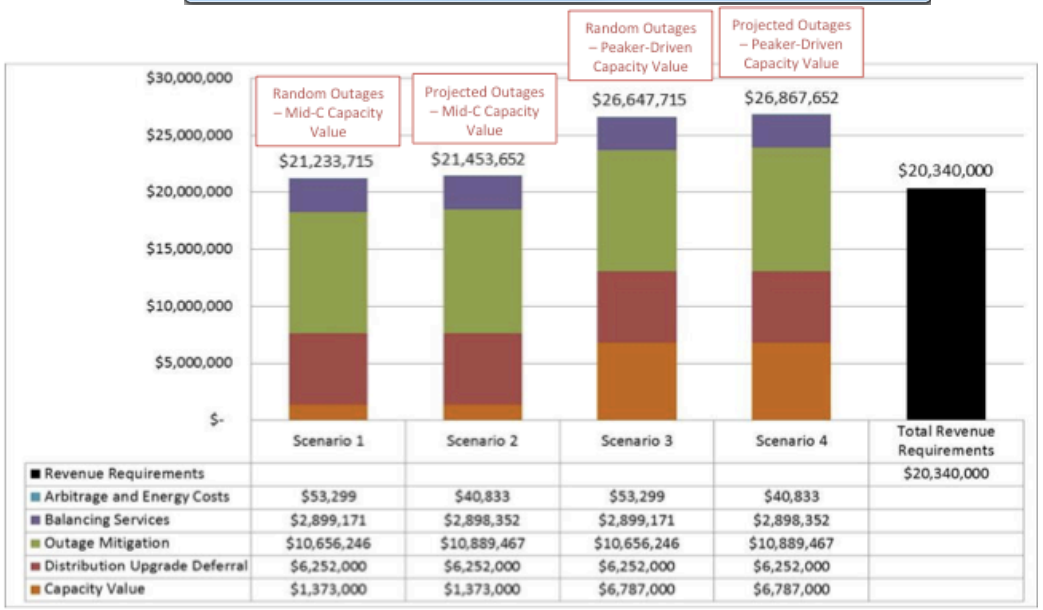
- *Collaboration with BPA/Primus/Puget Sound Energy to analyze the value proposition of Energy Storage on Bainbridge Island, WA.*

Energy storage evaluated as alternative to new substation.



Analysis tool developed to optimize use and the value derived by energy storage serving multiple applications.



Final analysis determined that revenue requirement can be exceeded if energy storage is controlled to provide multiple services

BES JCESR:
Understanding/Control of Dendrite Formation on Li

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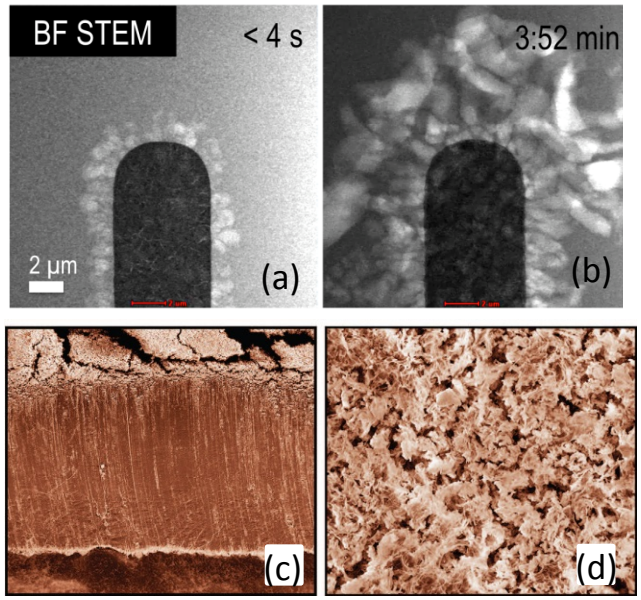

Morphology of Li deposition on metal electrodes. (a) and (b) direct observation of dendrite formation on metal electrode using in-situ TEM techniques. (c) and (d) Morphologies of dense Li film without dendrite formation after 500 cycle of charge-discharge in real batteries .

Reference Nano Letters, 15, 2168-2173, 2015; Nature Communications, 6, Article 6362, 2015.

Scientific Achievement

- Developed in-situ TEM characterization techniques to directly observe dendrite formation on Li anode, and new electrolyte to suppress dendrite formation in Li batteries.

Significance and Impact

- This research provides insight on how to use Li metal anode in advanced Li batteries and significantly increases the energy density and safety.

Research Details

- First observation of dendrite formation surface under operating conditions with nanoscale resolution.
- Intrinsic SEI's can Provide Protection for Li Metal. High Concentration Electrolyte Leads to Formation of Stable SEI Layers
- Coulombic efficiency is stable up to 6000 cycles.

Work was performed by Mehdi, Qian, J; Nasybulin, E ; Park, C ; Welch, DA; Faller, R; Mehta, H; Henderson, WA; Xu, W; Wang, CM; Evans, JE; Liu, J ; Zhang, JG; Mueller, KT; Browning, ND; Qian, JF; Henderson, WA; Xu,; Bhattacharya, P; Engelhard, M (; Borodin, O at Pacific Northwest National Laboratory

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EERE VTO Energy Storage - Analysis to Prototyping

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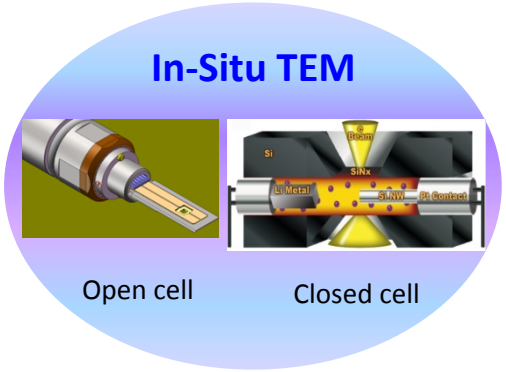
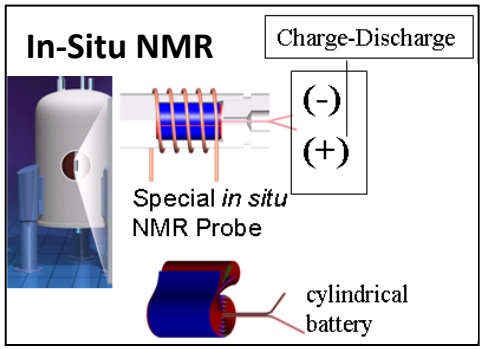
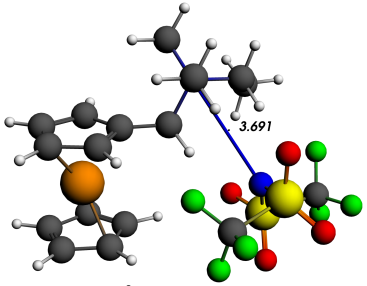
Analysis/simulation



Observe the structure change

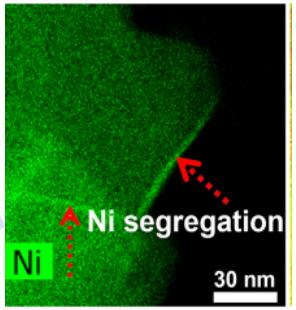


Track the composition changes

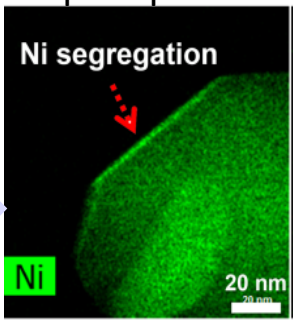


Simulation

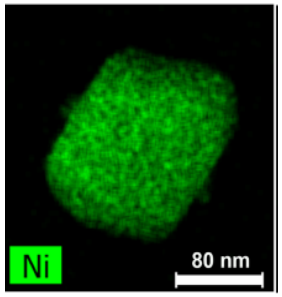
Versatile Synthesis



Co-precipitation

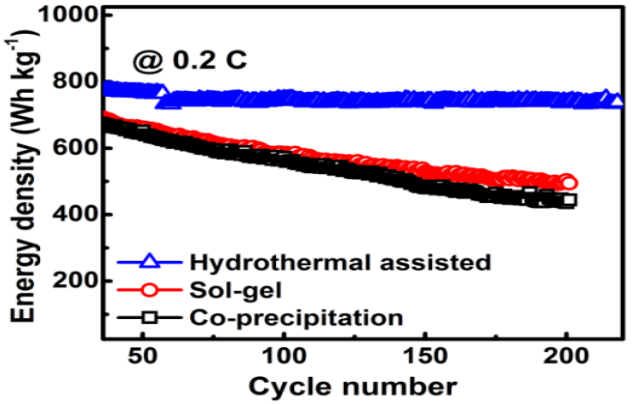


Sol-gel



Hydro-thermal

Synthesis Impact



Pouch cell prototype line

Electrode cast

Cell assembly

EERE VTO Energy Storage Si Anode Development

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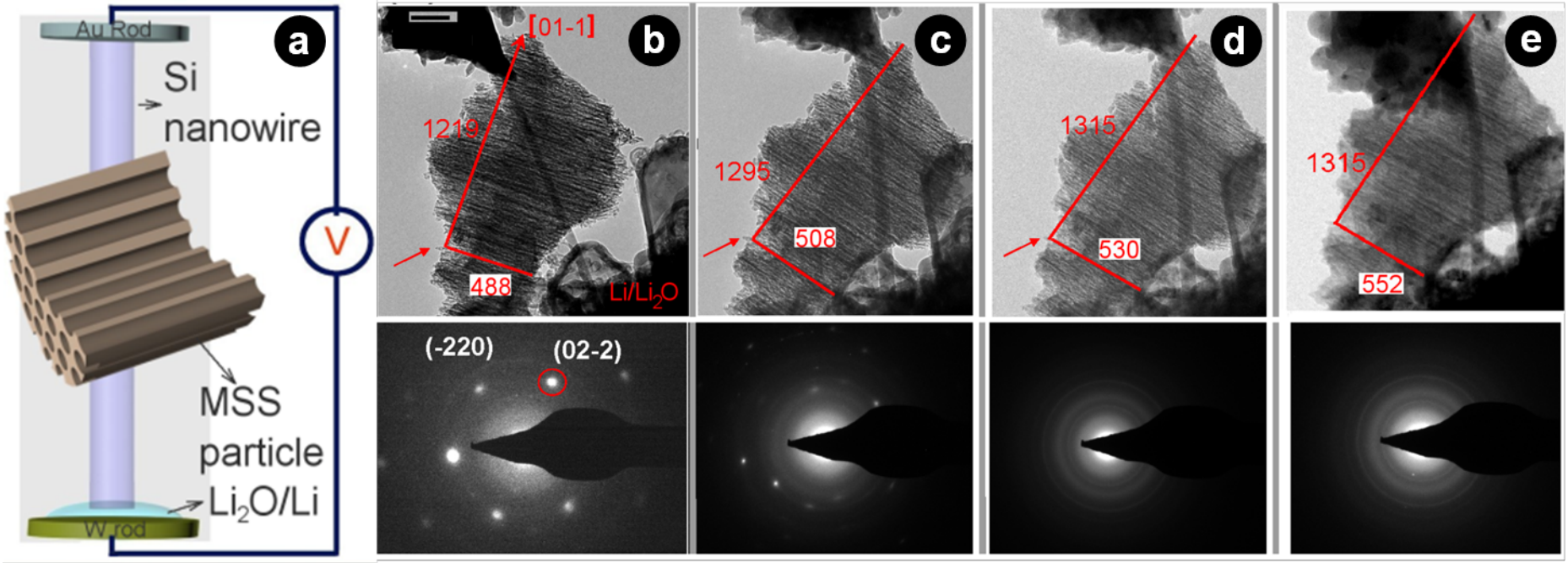
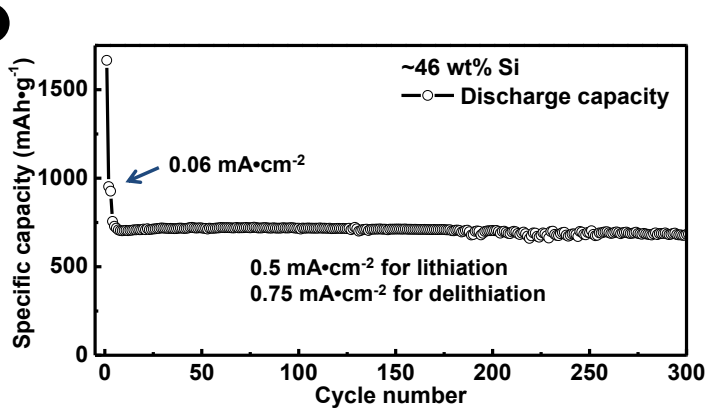
In-situ TEM study to show that the porous Si does not pulverize during repeated cycling and has small apparent volume change



The apparent volume change is ~30%

- The expansion along <100> direction (along the channels), is 13.1%
- The expansion along both <01-1> and <011> directions (perpendicular to the channels), is 7.8%



- ~750 mAh/g
- ~1.5 mAh/cm^2
- ~90.7% capacity retention over 300 cycles.

Acknowledgements

- Program Sponsors
  - OE Energy Storage Program
  - VTO Energy Storage
  - BES JCESR
  - USCOE

- Energy Storage Staff at PNNL
  - Wei Wang, David Reed, Ed Thomsen, Zimin Nie, Xiaoliang Wei, Bin Li, Alasdair Crawford, Yuyan Shao, Yuliang Chao, M. Vijayakumar, Jin Yong Kim, Xiaochun Lu, Guosheng Li, Vish Viswanathan, Daiwon Choi, Xioalin Li, Wentao Duan, Jamie Kizewski, Michael Kintner-Meyer, Patrick Balducci, Rebecca O'Neil, Di Wu, David Conover, Landis Kannberg. Jie Xiao, Wu Xu, Xiaolin Li, Chongmin Wang, Jianming Zheng, Jiangfeng Qian, Xilin Chen, Fei Ding, Meng Gu, Eduard Nasybulin, Ruiguo Cao, Yaohui Zhang, Mark H. Engelhard, Maria Sushko, Jian Zhi Hu, Suochang Xu, Chuan Wan, Mary Y. Hu Mark Gross, Gordon L. Graff, and Jun Liu